

Hydration and Dehydration in Carbonaceous Chondrites. R. N. Clayton¹, T. K. Mayeda¹, H. Kojima², M. K. Weisberg³, and M. Prinz³, ¹Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA, ²National Institute for Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173, Japan, ³American Museum of Natural History, New York, NY 10024, USA.

Aqueous alteration of anhydrous ferromagnesian silicates to produce phyllosilicates is a major process in the formation of CM and CI carbonaceous chondrites, and may also play a role in the history of CV and CO chondrites. It has also been recognized that the reverse process of metamorphic dehydration of phyllosilicates has also occurred in some meteorites [1, 2] and may be much more widespread than previously thought [3]. Oxygen isotopes provide a powerful tool for the study of hydration and dehydration reactions. In hydration reactions, stoichiometry requires the addition of 25–30% more oxygen than was present in the anhydrous assemblage; this oxygen is likely to have been derived from a large external reservoir with a distinctive isotopic composition; low-temperature hydration processes involve large mass-dependent isotopic fractionations. On the other hand, dehydration reactions do not have a large external oxygen reservoir, and occur at higher temperatures with correspondingly smaller isotopic fractionation effects. Thus the isotopic effects of dehydration are not the reverse of the hydration effects. The cycle from anhydrous minerals to hydrous minerals and back to anhydrous minerals should leave a distinctive isotopic record.

Metamorphic dehydration has been proposed for several different meteoritic occurrences: whole meteorites, such as B-7904, may be almost completely dehydrated [4]; meteorites may be partially dehydrated, such as Y793321 [1]; olivine-rich dark inclusions in CV3 chondrites may have been formed by dehydration [3]; fayalitic rims on chondrules and

on forsteritic olivine grains are additional candidates [3]. Krot et al. [3] suggest that the entire matrix of Allende has gone through the olivine-phyllsilicate-olivine cycle.

The broad view of oxygen isotope behavior in carbonaceous chondrites (Fig. 1a) is relatively simple, resulting from interaction of two oxygen reservoirs: a solid (dust) component with high ¹⁶O at the lower left, and a nebular gas component with low ¹⁶O at the upper right [5]. A linear mixing relationship extends from –40‰ to 0‰, defined by high-temperature exchange of anhydrous minerals from CV (mostly Allende); a break in slope occurs for more positive $\delta^{18}\text{O}$ values, due to the increased importance of mass-dependent fractionation in low-temperature processes. In CV chondrites with observed phyllosilicates in the matrix, such as Bali, Kaba, and Mokoia, the isotopic compositions of the matrix grade continuously into typical CM compositions (Fig. 1b; see also ref. 6). New data on separated matrix samples are given in Table 1. In each case, the matrix is somewhat depleted in ¹⁶O with respect to the bulk composition, reflecting the presence of ¹⁶O-rich refractory materials in the bulk samples. In addition, the isotopic compositions of dark inclusions [6, 7, 8] follow the same trend and cover the same range as compositions of CM chondrites. Thus, all of these materials have isotopic compositions indicating low-temperature interaction with water (liquid or vapor). These data alone do not indicate whether the interaction resulted in formation of a phyllosilicate phase. The modest degree of heavy-isotope enrichment in the Allende matrix, which bears

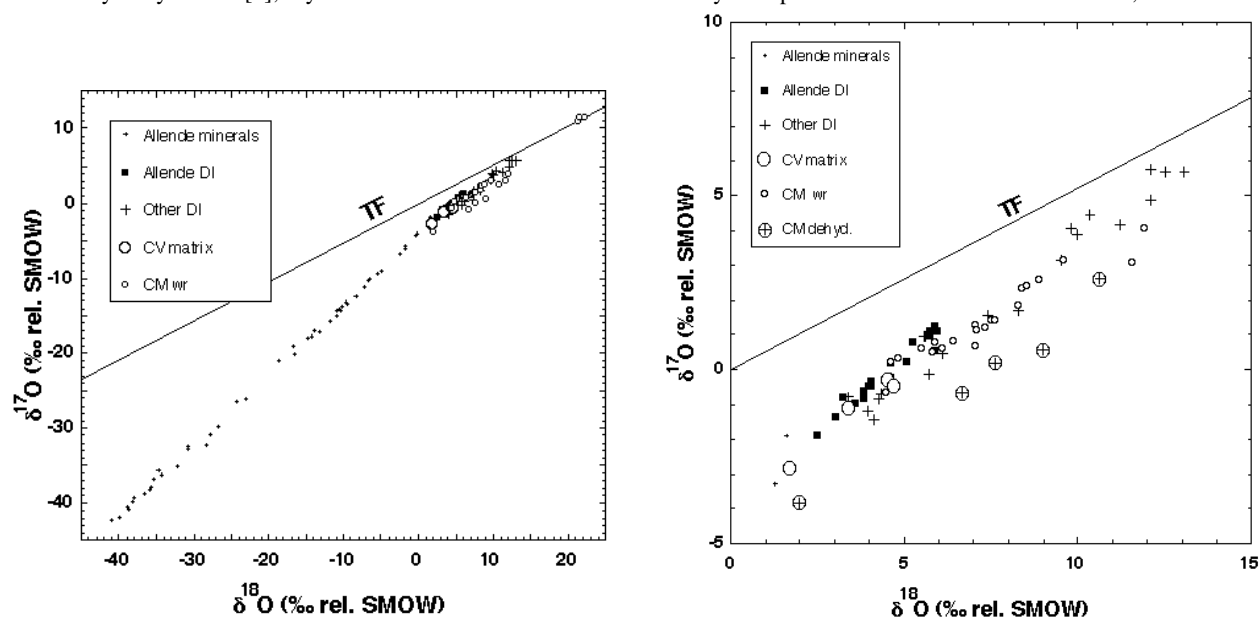


Figure 1. Three-isotope graphs for oxygen in carbonaceous chondrites. 1(a) shows mixing lines resulting from interaction of dust and gas reservoirs; 1(b) shows transition from CV to CM meteorites due to low-temperature aqueous alteration. Circles with crosses are “metamorphosed” CM.

Table 1
Oxygen Isotopic Compositions of CV Matrix

Meteorite	Whole-rock		Matrix	
	¹⁸ O (‰)	¹⁷ O (‰)	¹⁸ O (‰)	¹⁷ O (‰)
Allende	1.51	−2.73	3.41	−1.10
Kaba	2.18	−2.37	4.71	−0.46
Mokoia	3.52	−0.91	4.52	−0.28
Ningqiang	−0.11	−4.61	1.72	−2.82

a petrologic similarity to the dark inclusions, does not suggest large-scale hydration and dehydration.

On the basis of detailed TEM studies of several Antarctic CM chondrites, Akai *et al.* [9] subdivided the samples into “metamorphosed” and “non-metamorphosed” groups. They observed degradation of the phyllosilicate structures, but the chemical analyses of the whole meteorites (where correlated) show that the extent of dehydration is by no means complete. Oxygen isotopic compositions of these samples are given in Table 2, and are plotted in Fig. 1(b). Meteorites in the “non-metamorphosed” category all have isotopic compositions in the usual CM range; meteorites in the “metamorphosed” category all have ¹⁷O values more negative than the CM group, and occupy a field in the three-isotope plot which was previously empty. There is no reason to suspect that this unusual behavior is a result of Antarctic weathering. It is also unlikely that the low ¹⁷O is a consequence of dehydration, since the extent of dehydration is small, and a projection along a slope-1/2 fractionation line to a potential precursor leads to no known materials. The trend of the main-group CM chondrites in Fig. 1(b) is well-defined; the slope is slightly temperature-dependent, but is controllable primarily by the isotopic compositions of the solid and fluid reservoirs [10]. Thus the simplest explanation for the “metamorphosed” group is an origin in a different parent body from the main CM group. Too little is yet known about the chemistry and petrography of these rocks to test this hypothesis further.

Table 2
Oxygen Isotopic Compositions of CM Chondrites

	Meteorite	¹⁸ O	¹⁷ O	¹⁷ O	Wt. % H ₂ O
		(‰)	(‰)	(‰)	
Nonmeta- morphosed	A881594	5.81	0.53	−2.49	—
	A881655	7.05	1.30	−2.37	3.9
	A881955	6.09	0.59	−2.58	18.8
	Y793595	8.29	1.86	−2.45	—
	Y82042	8.49	2.39	−2.02	21.3
Meta- morphosed	A881334	6.69	−0.68	−4.16	18.3
	Y793321	10.62	2.58	−2.94	9.2
	Y82054	1.96	−3.82	−4.84	—
	Y82098	7.65	0.17	−3.81	—
	Y86695	9.01	0.55	−4.14	—

Additional meteorites may belong to the metamorphosed group. Other little-studied meteorites with low ¹⁷O are Cimarron and MAC88100 (and possibly Banten) (see Fig. 1(b)). The exceptional group of metamorphosed carbonaceous chondrites: B7904, Y82162, and Y86720 have very high ¹⁸O and ¹⁷O (Fig. 1(a)), and could fit either the main-group or metamorphosed-group trend. Their isotopic compositions require very high water/rock ratios (~1) during aqueous alteration.

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